US Navy Wastewater Membrane Treatment Systems

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Outline

- Magnitude of Navy Wastewater
- Graywater and blackwater
  - Background
  - Current Projects
- Oily waste water
  - Background
  - Current Projects

Magnitude of Navy Ship Wastewater

Blackwater (human wastes)

- 3 gallons/day/person
- 12,300 gallons/day on cruiser (CG-47, gravity flush), 1,200 gallons/day on destroyer (DD-963, vacuum collected)
- 189,000 gallons/day on aircraft carrier (CVN-68) with gravity flush

Graywater (drains from showers, sinks, scullery, etc.)

- 30-50 gallons/day/person
- 12,000 gallons/day on cruiser (CG-47) & destroyer (DD-963)
- 189,000 gallons/day on aircraft carrier (CVN-68)

Oily wastes (function of ship design & mission)

- Bilgewater
  - <2,000 gallons/day for new destroyer (DDG-51)
  - 5,000 gallons/day for cruiser (CG-47) & other destroyer (DD-963)
  - 20,000-50,000 gallons/day for aircraft carrier (CVN-68)
- Ballast water from compensated fuel ships
- Waste oil

NAVSEA Carderock Blackwater and Graywater Treatment Program

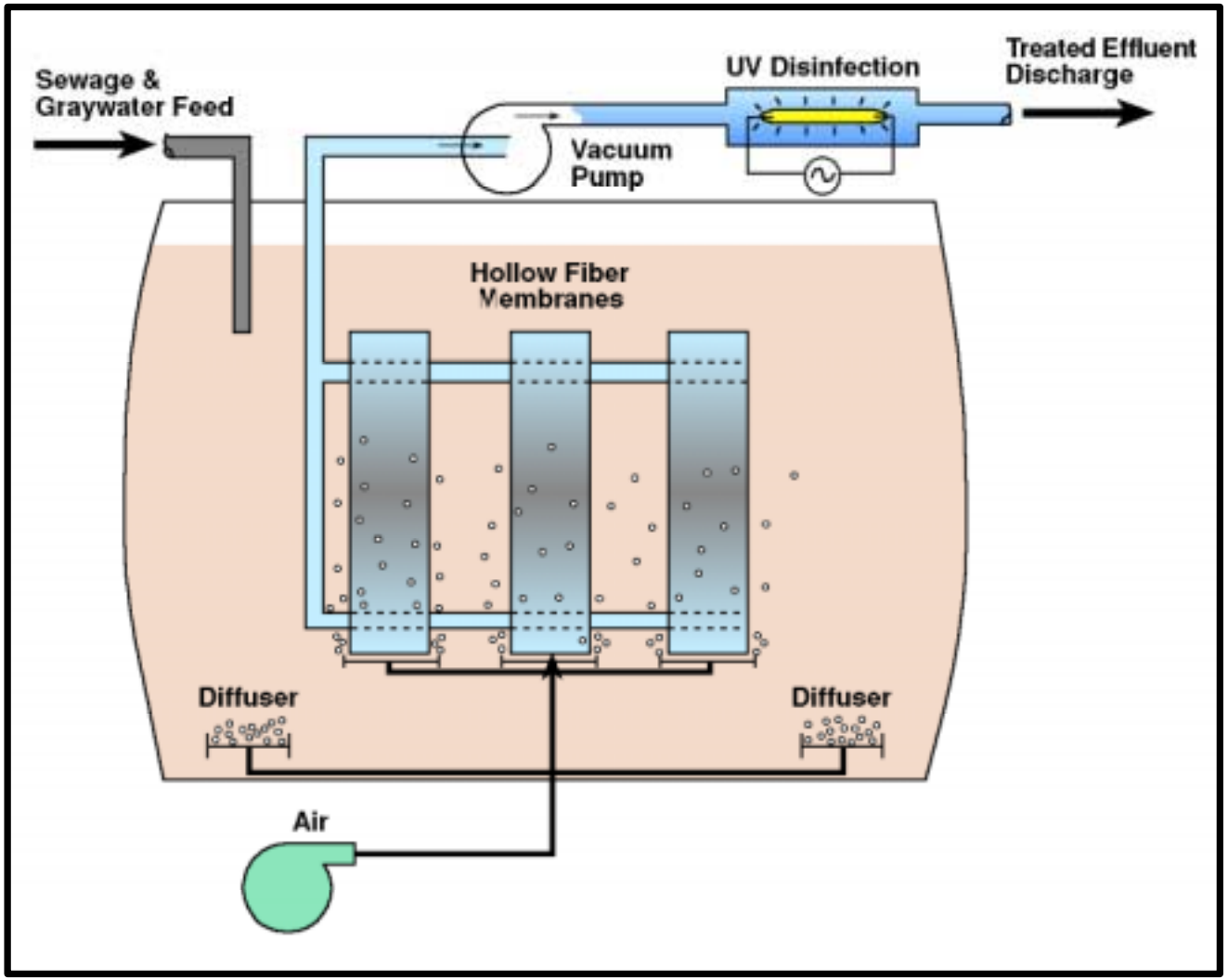
Background

- For the past several years, NSWCCD has been making efforts in the research, development, testing and evaluation (RDT&E) of graywater and graywater/blackwater treatment systems
- RDT&E goals
  - Biochemical Oxygen Demand (BOD_5): <50 mg/L
  - Total Suspended Solids (TSS): <100 mg/L
  - Fecal Coliform (FC): <200 cfu/100 mL
- Laboratory, pierside and shipboard evaluations evaluated membrane bioreactors with multiple purposes
  - Early tests to evaluate potential of membrane bioreactors for US Navy use
  - Recent tests performed on membrane bioreactors to validate a performance specification currently in development to serve as a standard for commercial systems to meet
  - FY04: shipboard and laboratory testing and evaluation of commercial systems against performance standard

Laboratory Facility

Capabilities:
3000+ gal/day wastewater
15000 gal+ wastewater holding
~40 ft x 12 ft available space

Basic Schematic of a Membrane Bioreactor



Laboratory Evaluations: Developmental Membrane Bioreactor

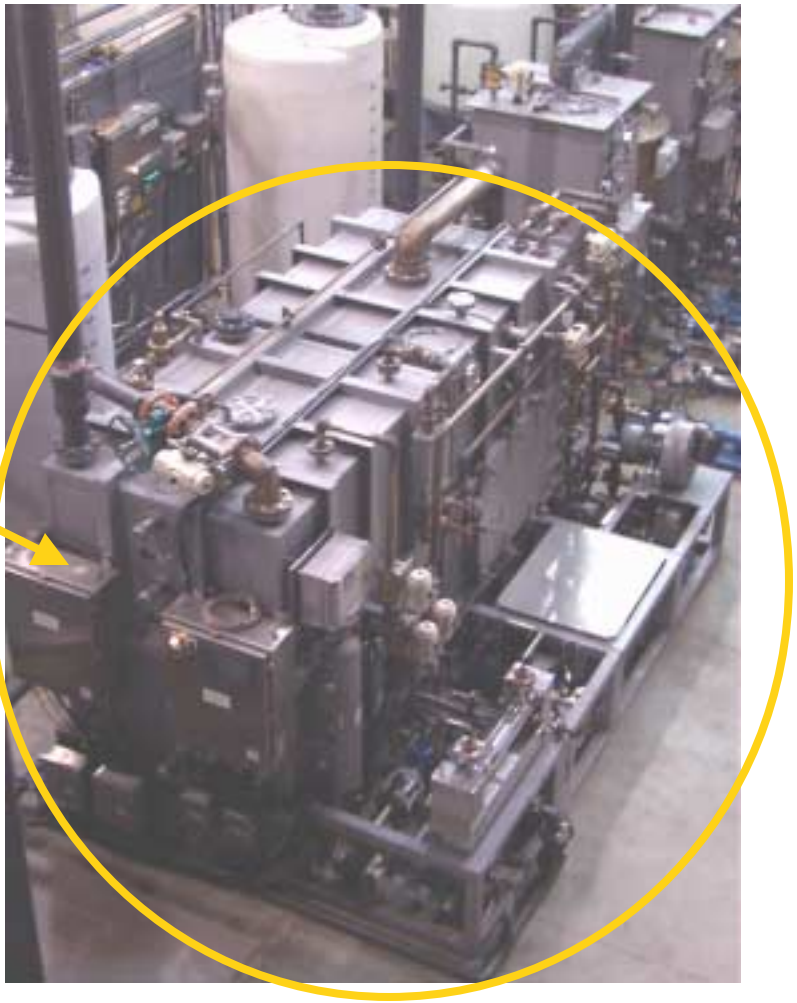
Laboratory Developmental Graywater Treatment Unit (DGTU) operated in preparation for shipboard system

Test Duration: 6 months continuous

Process Rate Achieved: 3000 gal/day

Dimensions: 15’ L x 8.3’ W x 8.8’ H

Weight: 38,000 lbs. wet



Shipboard Developmental Graywater Treatment Unit (DGTU) Evaluation

- Shipboard Evaluation

  - Objectives: Demonstrate 6-month operation without operator intervention or maintenance, process at rated system capacity, and meet effluent quality goals

  - Developmental Graywater Treatment Unit installation on USS BONHOMME RICHARD (LHD 6) completed in June 2001

  - System virtually identical to laboratory Developmental Graywater Treatment Unit, with remote lift stations installed to collect and deliver graywater (galley, laundry, showers and sinks)

  - Evaluation conducted over Jun 2001 - Sep 2002

  - Evaluation included 6-month overseas deployment

Shipboard Developmental Graywater Treatment Unit on the LHD-6 Amphibious Assault Ship

Combined Graywater/Blackwater Membrane Bioreactor Evaluation for Performance Specification Development

- Purpose
  - A performance specification is currently being written based on results of past laboratory, pierside and shipboard testing
  - Laboratory validation of the performance specification necessary to ensure that the Navy has a standard test method to evaluate commercial systems
    - Validation testing performed on the Developmental Non-oily Wastewater Unit (DNTU)
- Developmental Non-oily Treatment Unit (DNTU)
  - Modified from Developmental *Graywater* Treatment Unit (DGTU):
    - Tall bioreactor for combined blackwater and graywater treatment
    - Aeration feedback loop to reduce foaming
    - Solids feedback loop for automatic wasting
    - Membrane scouring equipment
    - Flat sheet membranes

Laboratory Developmental Non-Oily Wastewater Treatment Unit

Future Directions for Graywater/Blackwater

- Performance specification development and refinement
  - Performance specification will be updated from the lessons learned in the validation test
  - Application of performance specification to testing and evaluation of commercial systems
    - Macerator/chlorinator systems
    - Membrane bioreactors
    - Other biological, physical/chemical and advanced oxidation systems
- Further development of commercial-off-the-shelf database of wastewater treatment systems that compile key parameters for US Navy use
  - Performance
  - Feasibility in US Navy vessel environment
  - Cost

NAVSEA Carderock Oily Wastewater Treatment Program

Oily Waste Performance Problem Definition

- Improved ship design and bilgewater management practices have produced “dry bilge” ships
  - Reducing waste generation and bilge maintenance
  - Producing higher concentrations of bilge contaminants (detergents, AFFF, solids, etc.) and small oil droplets
- Increased contaminant concentrations in “dry bilge” can present challenges to current Navy parallel-plate separators

- Goal:
  - Develop a secondary treatment system to reliably achieve 15 ppm oil discharge limit without recycling
  - Reduce shoreside disposal costs and shipboard manning requirements

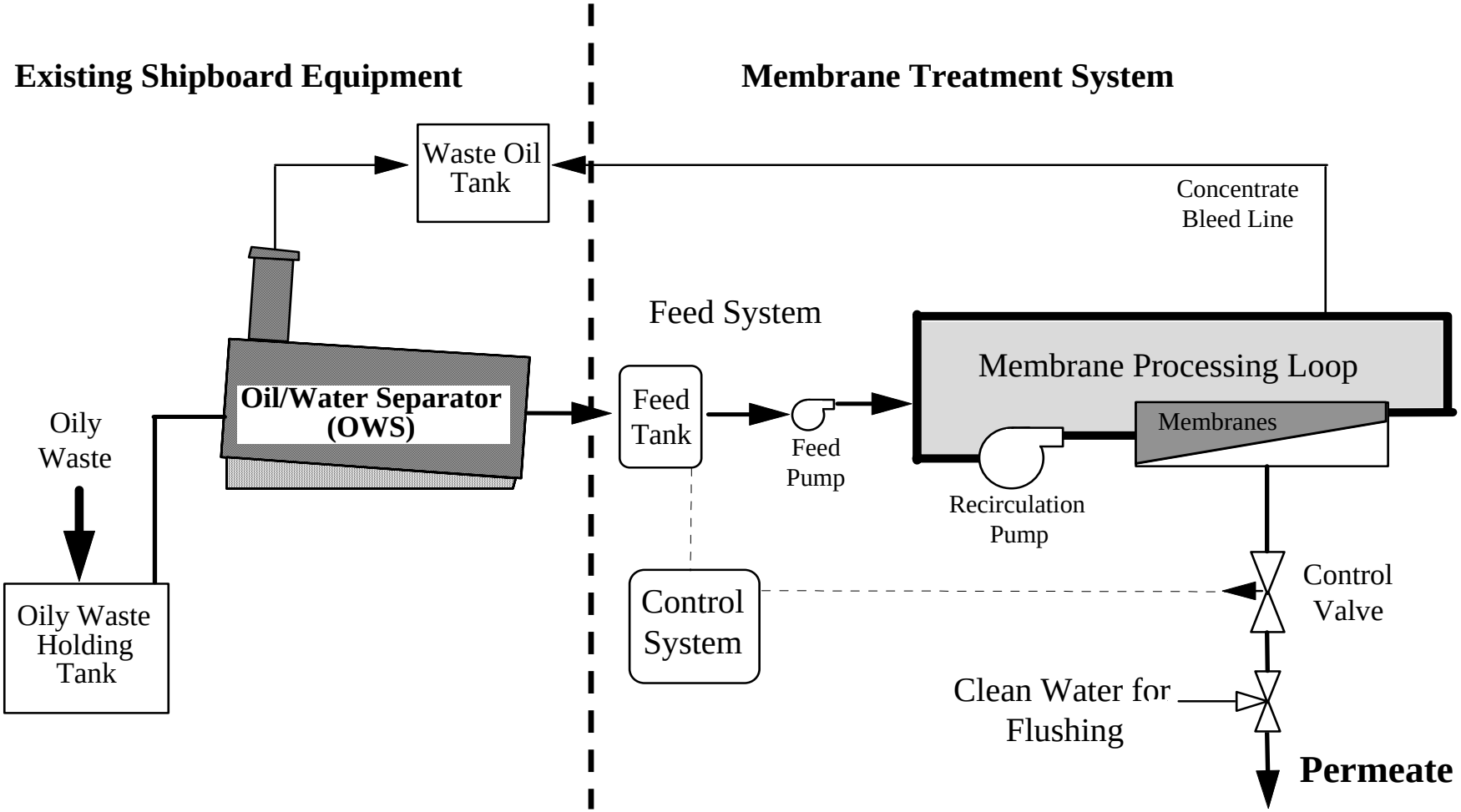
Technology Selection

- Multiple market surveys have identified several technologies to treat bilgewater aboard US Navy and Commercial ships
- Density (parallel plate) separation and ultrafiltration membrane technology selected for staged treatment system:
  - Density separation does an excellent job removing “bulk” oil
  - Ultrafiltration membranes selected for secondary treatment
    - Membranes very good at removing small, “emulsified” oil droplets
  - Both technologies resistant to chemical variations found in bilgewater
- Two technologies work well together, matching strength of one technology to weakness of other, resulting in a robust system
  - Reduce overall oil pollution abatement (OPA) system maintenance/manning requirements

Initial membrane evaluations

- Initial small-scale membrane comparison demonstration conducted at Naval Weapons Station Earle
  - Membranes processed oily waste from ships stationed at Earle
  - Ceramic membranes demonstrated chemical inertness and high fouling resistance
  - Polymeric membranes integrity failed with exposure to high level of bilgewater contaminant (acetone)
- Cross-flow ceramic ultrafiltration membranes identified as having the best potential

Oily Waste Membrane System Diagram



10 GPM Oily Waste Membrane Systems

- Two 10 gpm oily waste membrane systems have been successful demonstrated shipboard: a Prototype system aboard USS CARNEY (DDG 64) and an Engineering Development Model (EDM) aboard USS RUSHMORE (LSD 47)
  - Fully automatic operation, operating in series with parallel-plate oil / water separator
  - 100:1 volume reduction of oily waste

NAVSTA Mayport authorized ship to discharge overboard in port

<u>Test Results</u> USS CARNEY (DDG 64)

- Processed oil-water separator (OWS) effluent for over 70 months

  (700 hours of membrane system operation)
- Consistently met 15 ppm oil discharge limit (average of 3.5 ppm)
- Membrane replacement interval ~ 5 yrs expected
- Regeneration interval - 15 months

<u>Status</u>

- Continuing to evaluate regenerated membranes
- Membrane systems currently installed or being procured for DDG 89 & follow, in addition to LPD 17

Prototype 50 GPM Oily Waste Membrane System

- A prototype 50 GPM oily waste membrane system has been developed, based closely on the 10 gpm systems, to demonstrate a full-scale shipboard system and provide input to a 50 gpm membrane system performance specification
- Currently undergoing shipboard evaluation aboard USS IWO JIMA (LHD-7)
- Approximately 1 million gallons of oil-water separator (OWS) effluent processed so far with no effluent problems

Characteristics:

•System Flow rate: 50 gpm

•# of ceramic membranes: 12

•Power required: 50 Hp

•Modular design: 70 ft^2

Features:

•Self-Cleaning strainer

•Modular construction to facilitate installation

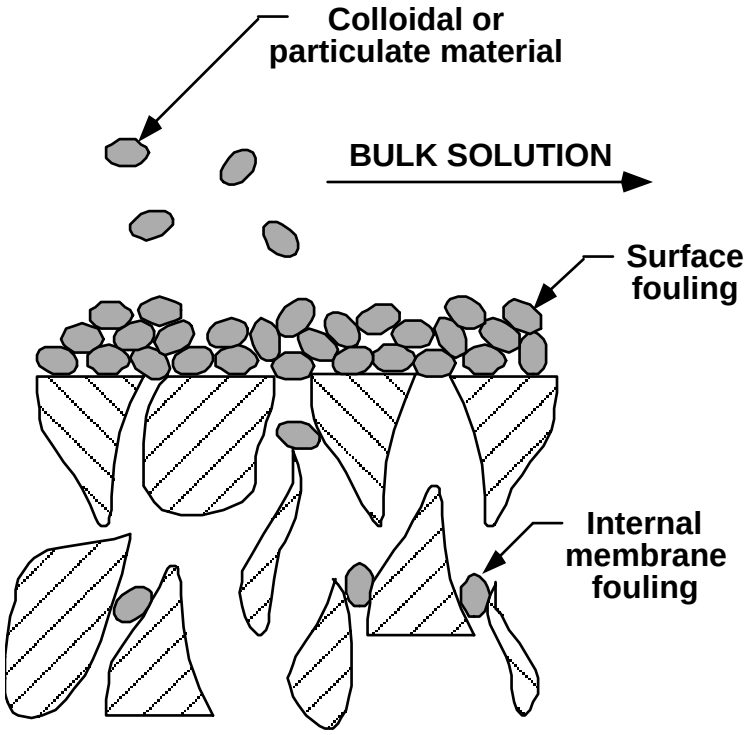
Fleet Procurement

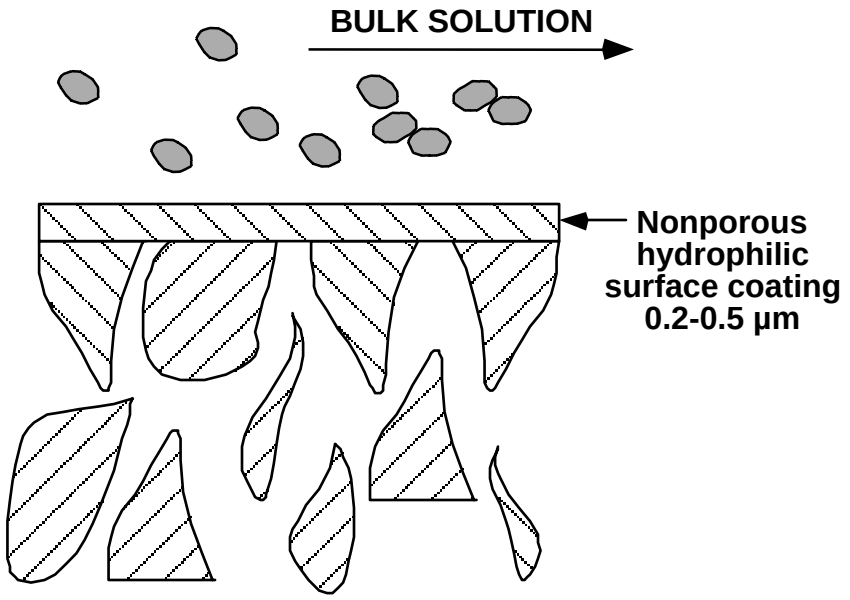
- Successful demonstrations aboard CARNEY and RUSHMORE have yielded performance specifications based procurements for three ship designs
  - **DDG 51**
    - Membrane systems currently installed or being procured for DDG 89 and follow (24 ships)
  - **LPD 17**
    - LPD 17 (7 ships), contract awarded, ship construction near completion
  - **CVN 77**
    - Contract awarded, installation underway

Nonporous Membrane

- Membrane acquisition costs and fouling rates have a direct impact on membrane system lifecycle costs
- Membrane and Technology Research, Inc. (MTR) has developed a nonporous polymer coating
  - Excellent resistance to a wide range of pH and wastewater contaminants
  - Reduces surface and internal fouling of membranes

Nonporous Membrane Technology





Conventional Finely Porous Membrane

Composite Membrane with Nonporous MTR Coating

Polymeric Nonporous Membrane

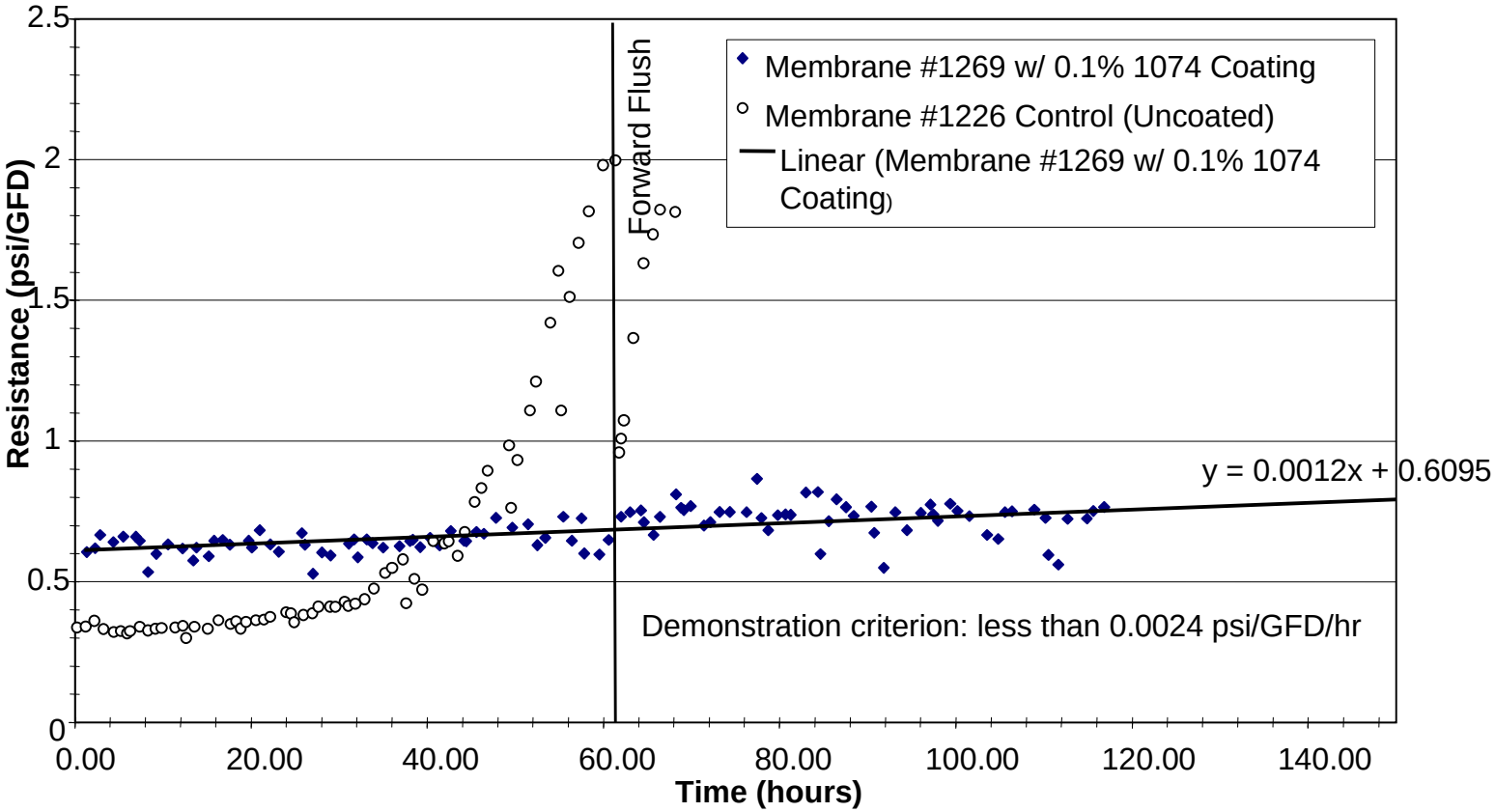
- Membrane and Technology Research, Inc. performed testing on a polymeric spiral-wound membrane
  - Potential to perform equivalent to ceramic membranes
  - Polymeric membrane costs less than ceramic membranes
- Reduce acquisition costs of membrane system
  - Improve fouling resistance of membranes
  - Low cost membranes

Nonporous Membrane Demonstration – Upcoming Studies

- Evaluation of coated commercial ceramic membranes
  - Demonstrate the feasibility and effectiveness of coating in the laboratory
  - Demonstrate the improved fouling resistance and process reliability in full-scale shipboard evaluations
- Evaluation of redesigned polymeric spiral-wound modules
  - Design spiral-wound modules compatible to NAVSEA open systems architecture
  - Demonstrate long-term system performance

Test Site – Carderock Small-scale Evaluation Test Loop

Results of Small-scale Ceramic Membrane



- Sample analysis results
  - Permeate <5 ppm (mg/L), 2 samples
  - Feed ~100 ppm (mg/L), 2 samples

Organic Breakthrough

Sample	Benzene		Toluene		Ethyl-Benzene		Xylene, Total		Oil and Grease	
Molecular weight	78.11		92.06		106.07		106.17		---	
	Feed	Perm	Feed	Perm	Feed	Perm	Feed	Perm	Feed	Perm
Average (BTEX – ppb, O&G - ppm)	50	31	193	92	133	35	655	178	4500	4
Efficiency	37%		52%		74%		73%		99.9%	

- Measured permeate for BTEX (benzene, toluene, ethyl-benzene and xylenes) organics to determine efficiency of removal
  - The coated membrane processed a high concentration of synthetic bilgewater at the operating parameters of the membrane system
- BTEX organic concentrations were reduced
  - Efficiency increased as molecular weight increased

Future Developments - Technology Improvements

- Membrane acquisition costs and fouling rates have a direct impact on membrane system lifecycle costs
- Lower cost
  - In-tank membranes cost approximately $16,000 to $18,000 for a 3,000 gal/day graywater treatment system
  - Full-scale ceramic membranes cost approximately $65/sq.ft.
    - 300 sq.ft. required for 10 gpm (oily waste treatment system)
  - Reduce membrane cross-flow/aeration rate
    - Reduce number of pumps necessary for cross-flow
    - Simplify membrane system
- Reduce fouling (see ESTCP)
  - Increase time between chemical cleanings
  - Improve surface area to volume ratio